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14. ABSTRACT

A brief overview of Asphere Stitching Interferometry (ASI), Variable Optical Nulling (VON), large optic polishing using Magneto-Rheological Finishing (MRF), and a new aspheric surface representation are presented. ASI is a technique to measure aspheres without the use of null lenses. ASI was combined with VON to achieve fringes across an entire field. The technique was demonstrated on a 6 inch F/2.2 lens. A few pictures are presented of polishing done for the NASA Spherical Primary Optical Telescope (SPOT) using MRF. Also, reference is given to a new method of presenting mirror shape using orthogonal polynomials.

15. SUBJECT TERMS

Stitching, interferometry, variable optical null, asphere, orthogonal, polynomials

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MRF® developments & asphere metrology using VON™ Technology

presented to:

Mirror Technology SBIR/STTR Workshop

June 7th to 9th, 2010

Boulder, CO

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NASA: Scott Antonille, Dave Content, John Hraba, Phil Stahl, John West …

+ many DoD sponsors

Outline

- Asphere Stitching Interferometry (ASI™)
  - Variable Optical Null (VON™) Technology
- Large optic polishing with MRF®
- New aspheric representation

Background

- Asphere metrology typically requires dedicated – and costly – null lenses, which can often be the pacing element in optics manufacturing
- We are reporting here on a – NASA and DoD – SBIR success story in developing a metrology tool capable of:
  - Measuring concave or convex surfaces
  - Measuring flat, spheres and aspheres

  … *without* dedicated null lenses or tooling
  - For both surface measurements and, in some cases, transmitted wavefronts (e.g. flat & dome TWF)

Asphere Stitching Interferometer (ASI^{TM})

- Measure flats, spheres, and on-axis aspheres
  - Diameters up to 200 mm in all cases, up to 300 mm in most cases
  - Slopes up to 90 degrees, i.e. full hemispheres concave or convex

- Aspheric departures up to 1,000 waves (~630+ microns) from best-fit-sphere or more
  - Depends on profile and radius

- Automated part alignment and positioning

- ~1 meter of Z-axis travel for automated radius measurements (using cats-eye + stitching)

- High spatial resolution output maps
  - E.g. (500 x 500) pixels, (1K x 1K), (2K x 2K)…

  = Excellent lateral Frequencies capabilities
  Important for metrology of Mid Spatial Frequencies, tight Edge Exclusion, quilting errors etc

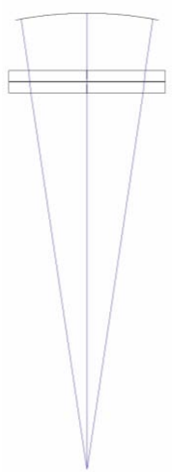
Variable Optical Null (VON^{TM})

- Counter-rotating optical wedges

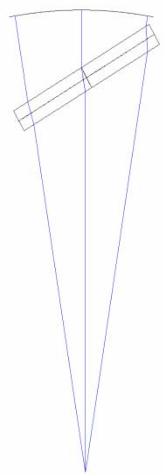
Plane-parallel Maximum wedge

- By varying the total wedge angle and tilt, the VON produces low-order aberrations:
  - Astigmatism, coma, trefoil

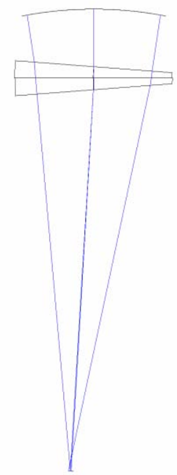
VON Configurations



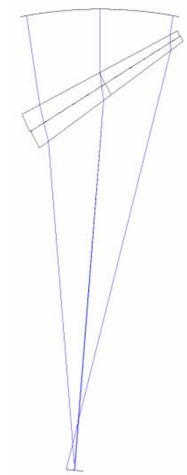
No Tilt
No Wedge



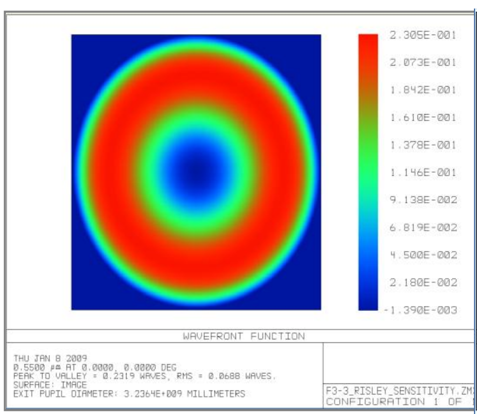
Tilt only



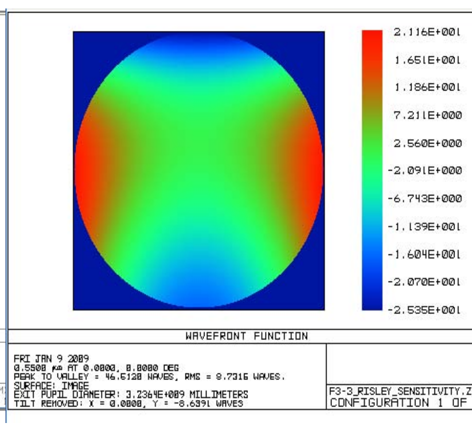
Wedge only



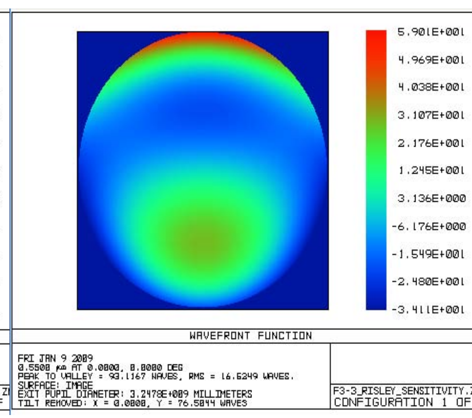
Tilt and
Wedge



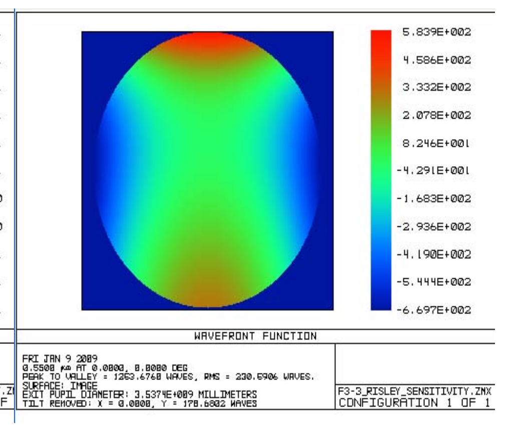
small
spherical



mostly
astigmatism



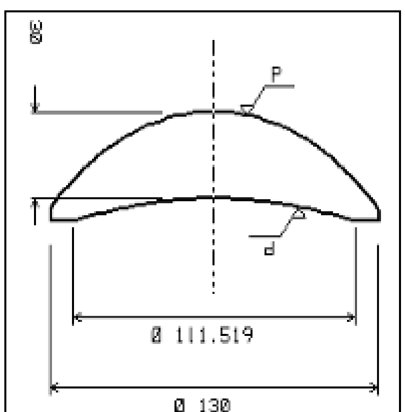
mostly
coma

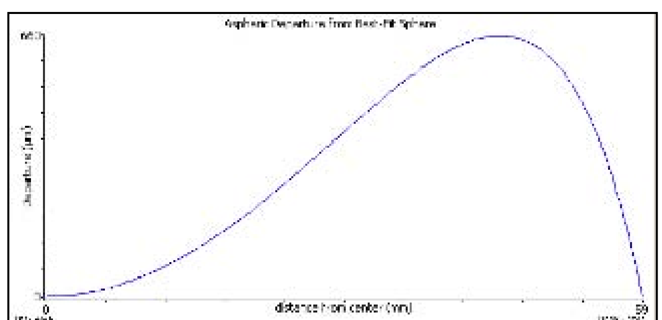


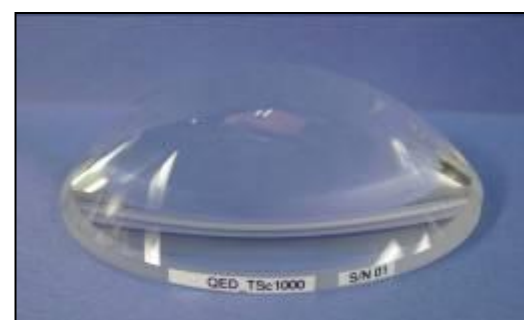
coma and
astigmatism

Example: 1,000 Waves Asphere

- 118 mm CA
- 72 mm vertex radius
- 656 micron departure from best fit sphere
- High NA and aspheric departure make this asphere difficult to measure with other techniques







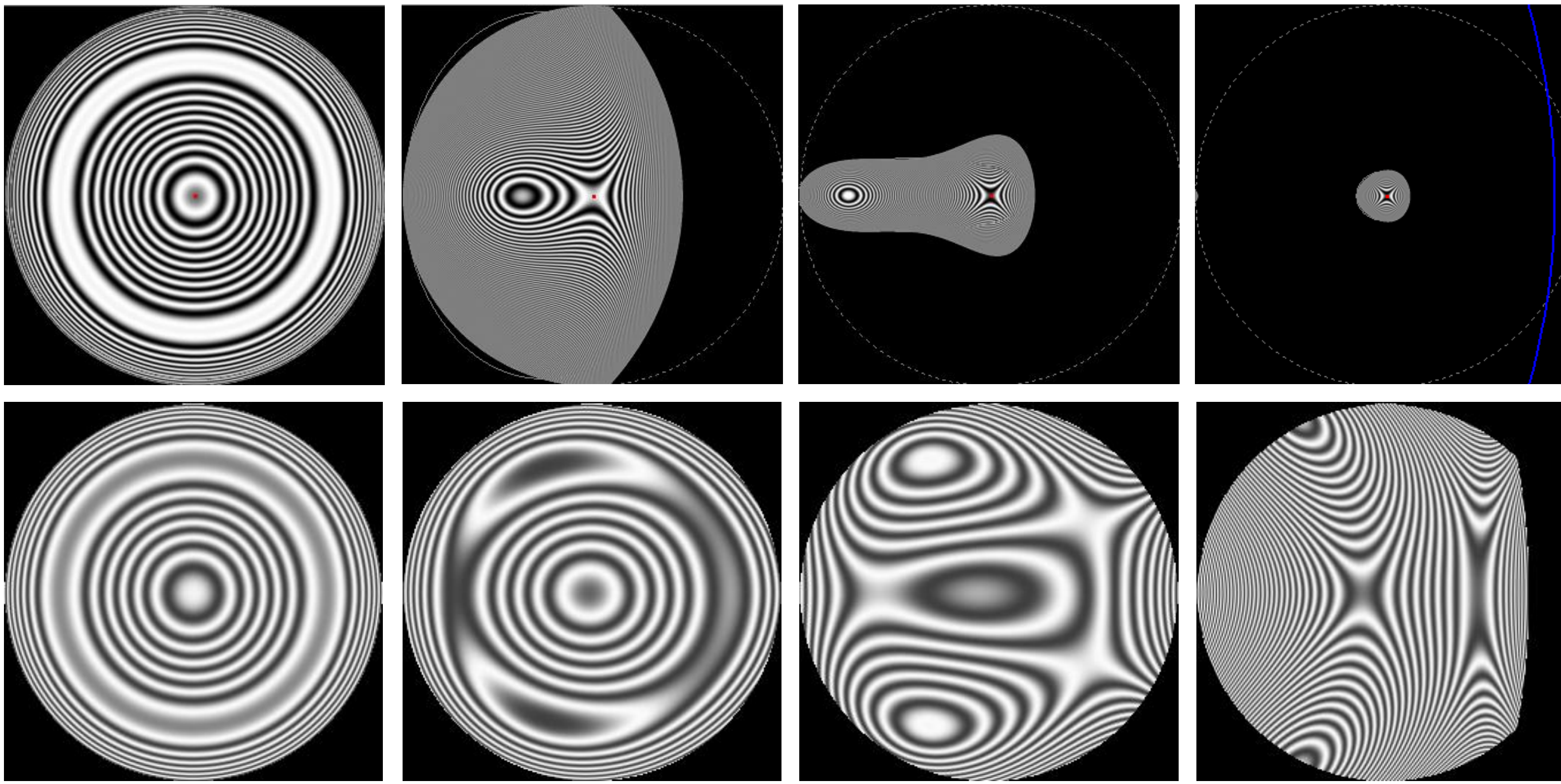
Variable Optical Null (VON) Device

See video…

R = 0 mm | R = 16 mm | R = 31 mm | R = 46 mm

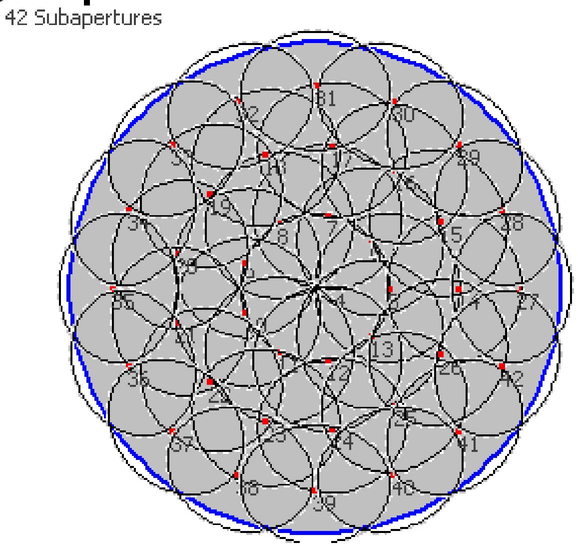
Without VON

With VON

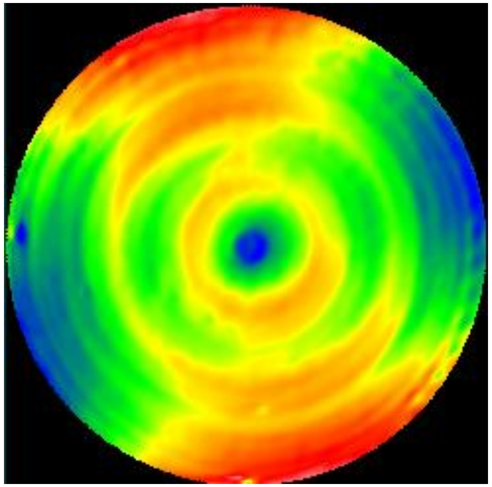


- Only need to match the low-order aberrations of each subaperture, producing resolvable fringes over entire field
- Combine measurement of residuals with nominal wavefront of VON

Measurement Results

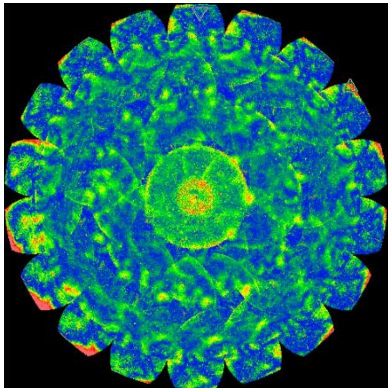


Measurement Lattice



rms = 147nm

- Measurement result using 6” F/2.2 transmission sphere
- ~40 subapertures
- ~15 minute measurement time
- Low mis-match error (3.6nm)



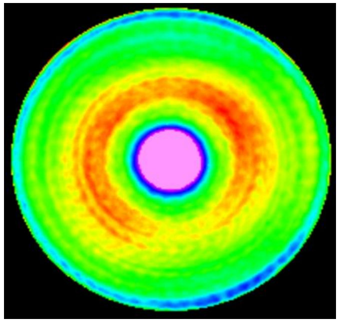
Mis-match map: rms = 3.6nm

PTB Asphere: Measurement Reproducibility and Repeatability

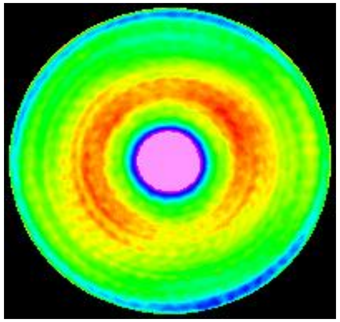
PTB Asphere - Part Id 014542-725-00
Diameter: 52.2 mm
Departure: 59 um (93 waves HeNe)
Base radius: 53.312 mm Convex

	Mean	Std. Dev.
PV	1.812 μm	0.028 μm
rms	0.278 μm	0.008 μm
R0	53.303 mm	2.3 μm

Comparison of measurement results between 6” F/2.2 and 6” F/3.2

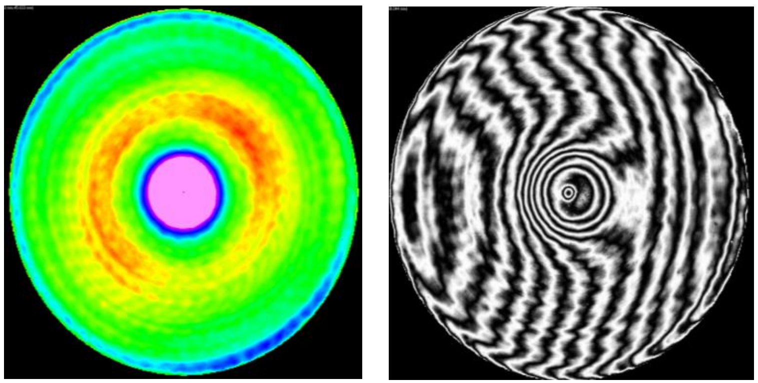


6” F/2.2
PV = 1.790 μm
rms = 0.278 μm
R0 = 53.308 mm

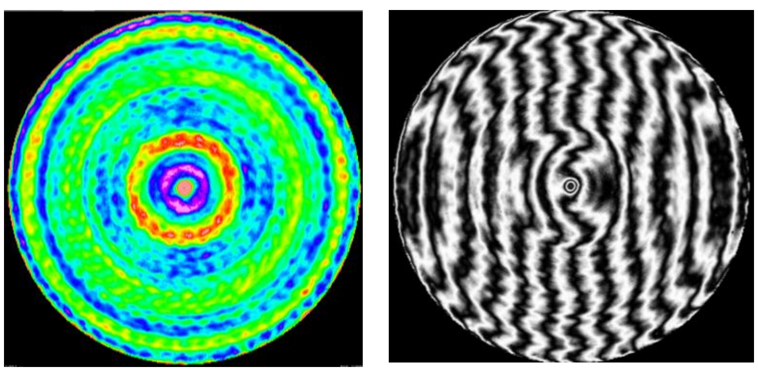


6” F/3.2
PV = 1.789 μm
rms = 0.279 μm
R0 = 53.303 mm

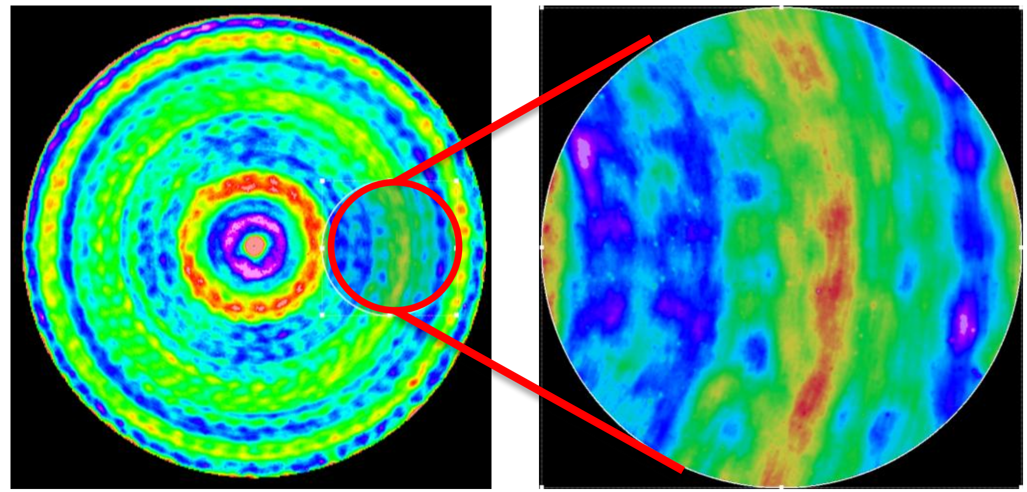
High Resolution Stitching



2000 x 2000 pixel stitch result using 6” F/3.2



2000 x 2000 pixel stitch result using 6” F/3.2
(36 Zernike terms removed to highlight mid-spatial frequencies)



15mm diameter area zoomed to show high resolution

Typical Measurement Times

- Set-up times:
  - Standard (known) lens: 1-2 minutes
  - Unknown lens: 4-8 minutes
- Measurement times:
  - Flats/spheres: 5-10 minutes
  - Mild aspheres: 10-20 minutes
  - Steep aspheres: 15-30 minutes
  - Depends largely on optimum transmission sphere availability

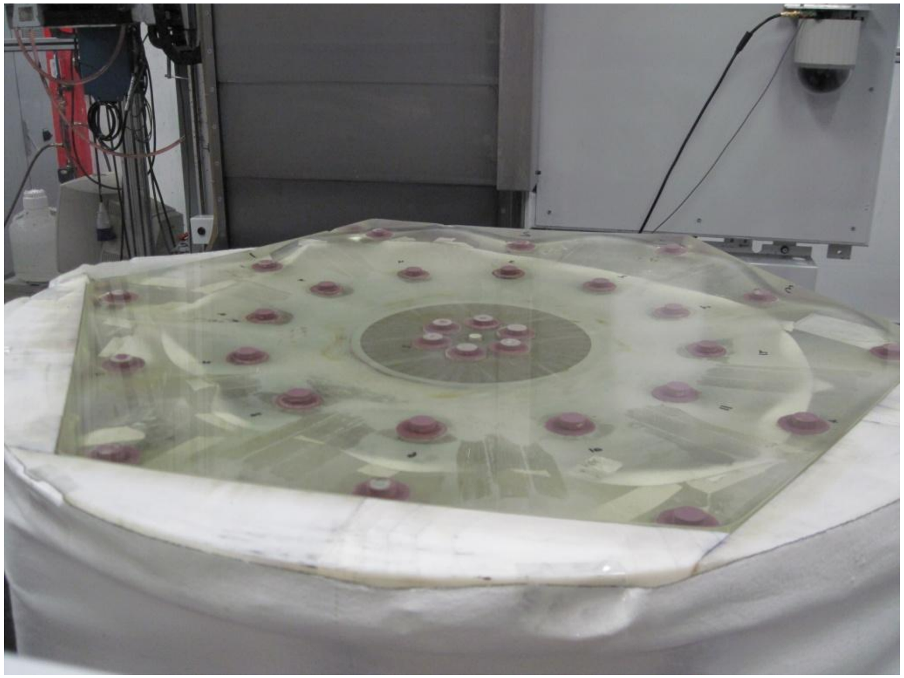
Current Limitations / Future work

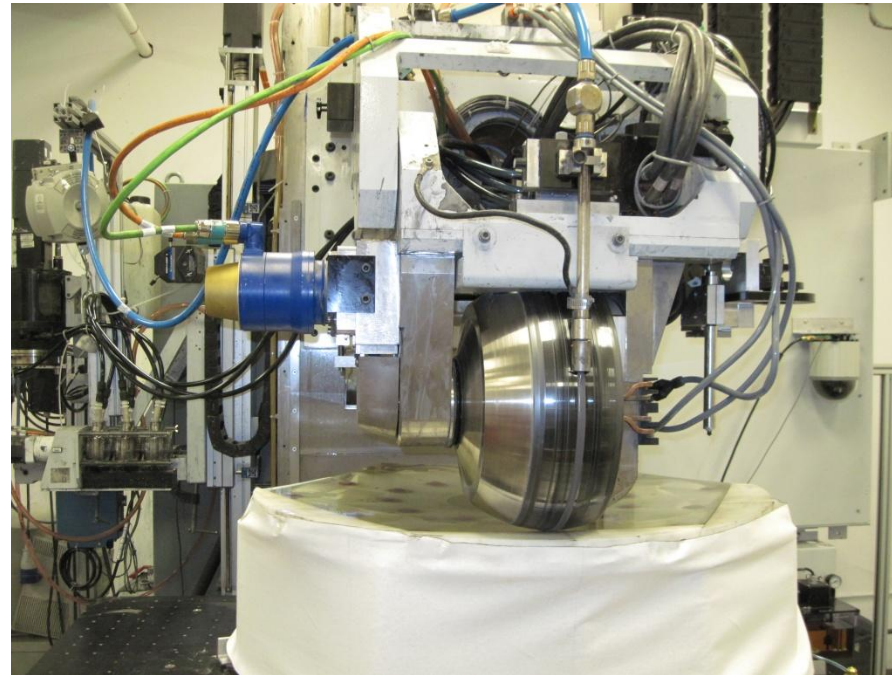
- On-axis (rotationally symmetric) aspheres only
  - Not a fundamental limitation, only current software
  - Very mild off-axis aspheres can be measured now
- No aspheres with inflection points
  - Future versions of the ASI with different VON designs could possibly measure these
- Can measure aspheres with center holes, as long as the central subaperture “sees” some of the part
- Bigger size ASI…

ASI® Summary

- The use of configurable null optics with subaperture stitching allows for:
  - Large aspheric departure measurement capability (up to 1000λ)
  - Shorter measurement times (fewer sub-apertures)
- While maintaining all of the original benefits of subaperture stitching interferometry:
  - Full aperture coverage
  - Higher lateral resolution
  - Increased accuracy
  - Aspheric measurements without dedicated nulls

NASA SPOT Mirror
MRF Polishing on Q22-950F machine

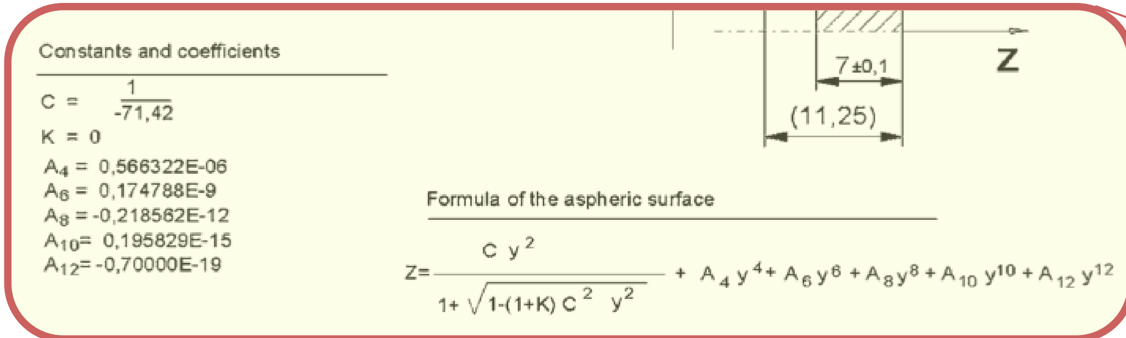




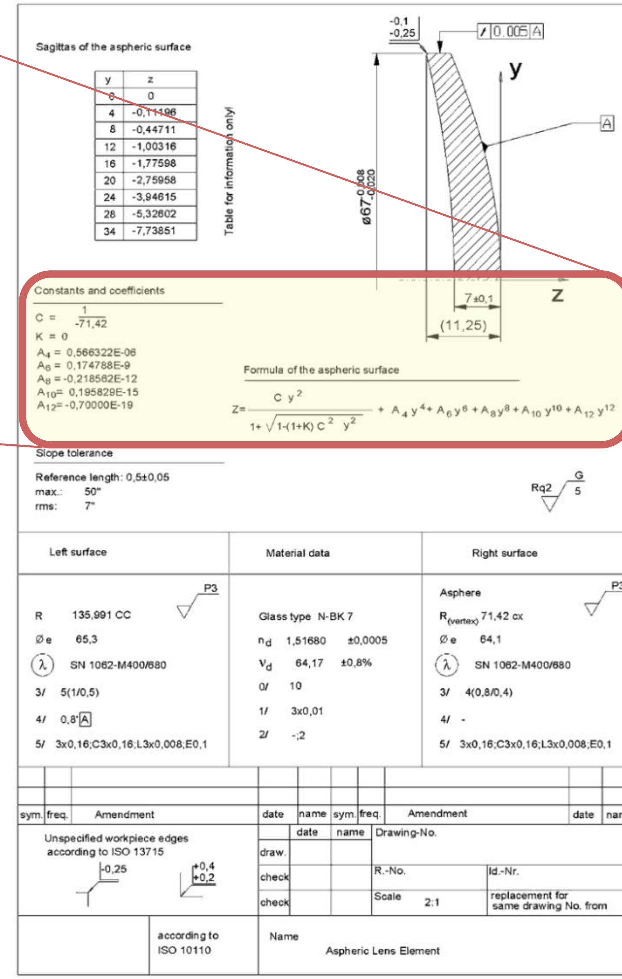
Shape: Hexagonal concave sphere
Material: Pyrex
Diameter: 870 mm
Wavefront specification: $\lambda/40$ rms
Initial wavefront error: 1.5 λ rms

See talk from John Hagopian and Jason Budinoff at NASA

Effective Characterization of an Asphere's Nominal Shape



$$Z=\frac{c\,y^2}{1+\sqrt{1-(1+K)\,c^2\,y^2}}+A_4y^4+A_6y^6+A_8y^8+A_{10}y^{10}+A_{12}y^{12}$$



Many issues with current representation:

- **Significant digits ?**
- **Accuracy ?**
- **Difficult to constraint etc.**

a more effective alternative ("Forbes Representation") has been developed with orthogonal polynomials. See www.qedmrf.com after 6/15/10 for details…

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